UK Research and Innovation

Loki Neutron Guide NBOA Specification

Contents

2 Attachments

SI-7611-001	NBEX Simplified Design - STEP
ESS-0106220.2	Loki NBOA drawing
ESS-0147089 Rev 1	ESS GUIDELINES FOR ACCESSING AND PERFORMING WORK ON SITE
ESS-0147100 Rev 1	Safety Training Matrix for Installation Activities on Site
ESS-0037830	Template ESS Project Quality Plan
ESS-0047989	ESS Rules for Quality Regulation for Mechanical Equipment RESSQ-Mech
ESS-0027134	Target Project Quality Plan

3 Introduction

This document outlines the requirements for the supply of the Loki neutron guide NBOA. The Loki NBOA guide will be installed at the ESS facility. The NBOA/NBPI/NBEX is a joint project involving ESS and UKRI. The guide delivered must meet UKRI and ESS requirements.

This document outlines the key guide requirements and sets boundaries for the scope of the project for the purposes of tender and contract definition.

The NBOA will fit within the NBPI which will form a part of the ESS target systems. The quality standards for the ESS target systems are outlined in the documents ESS-0047989 and ESS-0027134.

4 Definitions

UKRI	UK Research & Innovation (contract customer) - formerly STFC
STFC	Science Technology and Facilities Council
RAL	Rutherford Appleton Laboratory - The UKRI site where the customer staff are based (Oxford, UK)
ISIS	The Neutron and Muon Source at RAL
ESS	European Spallation Source – (Lund, Sweden)
NBOA	Neutron Beam Optical Assembly - See Figure 1
NBPI	Neutron Beam Port Insert - See Figure 1
NBEX	Neutron Beam Extraction - See Figure 1
PDR	Preliminary Design Review
CDR	Critical Design Review
FDR	Final Design Review

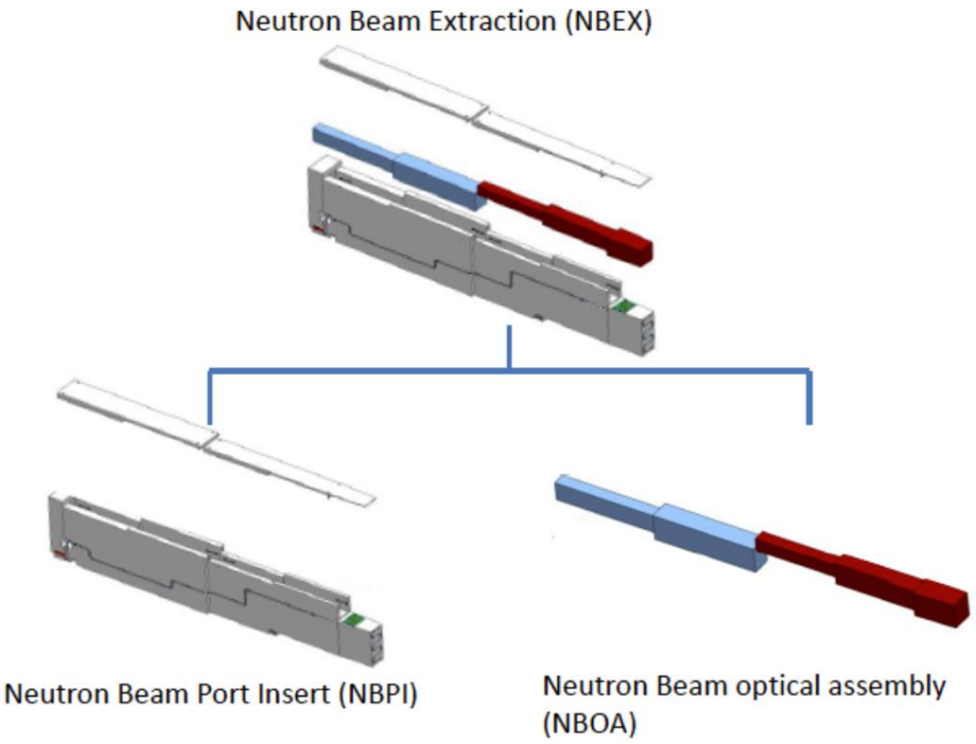

Figure 1 – Generic NBEX Breakdown (not representative of Loki)

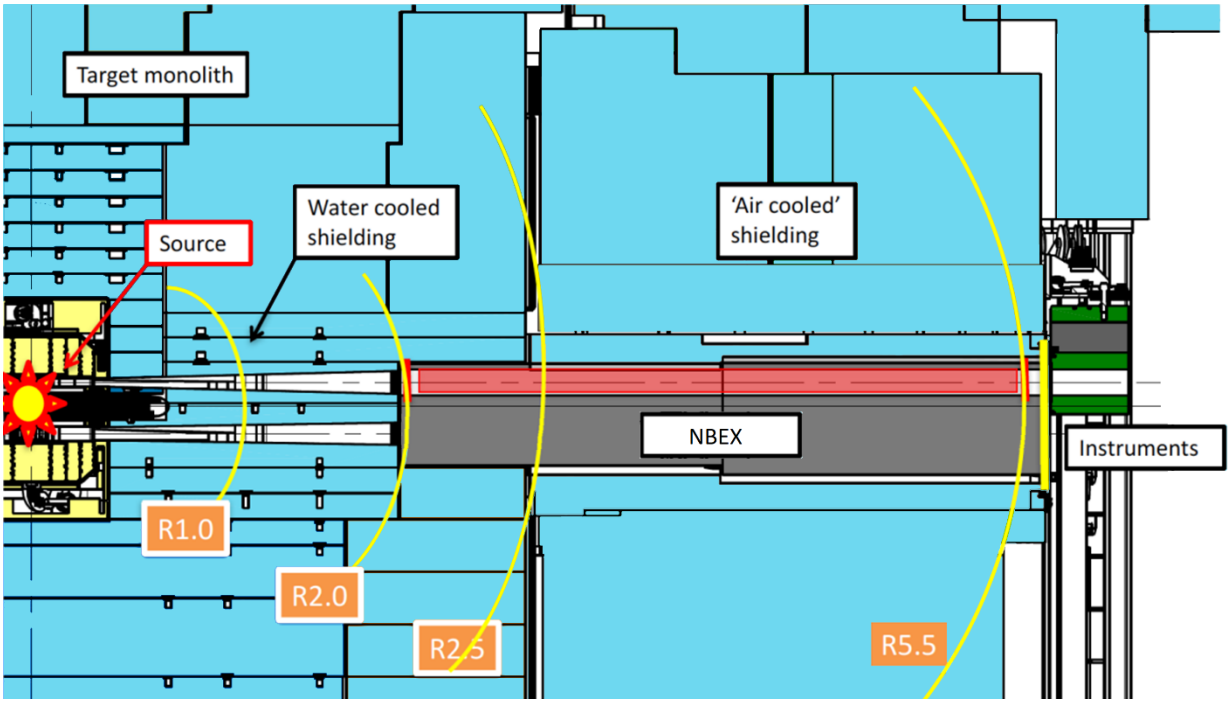

Figure 2 – NBOA in context

5 Scope

The Supplier will be responsible for designing, manufacturing and delivering the NBOA for the Loki instrument. The NBOA design must be optimized to the requirements outlined in this document and meet UKRI approval. The NBOA includes:

- Neutron guide
- Alignment devices

The Supplier will also be responsible for installing and aligning the NBOA within the NBPI assembly at the ESS site in Lund. The alignment requirements are outlined within this document. As a part of this the Supplier will be responsible for the design and delivery of any specialised tooling that is required for alignment & installation in the NBPI.

The supplier will be responsible for defining, implementing, and documenting the results of, the quality control and assurance plan, in line with the requirements outlined in Section 7

The Supplier will be responsible for delivering the project documentation outlined in Section 5.1.

5.1 Documentation

As a part of the contract the Supplier must provide:

- Detailed drawings of the NBOA
- Documentation for PDR, CDR, FDR and inspection report review as detailed in Section 9
- 3D as built models (STEP format)
- Inspection reports, as detailed in Section 7.7 and Section 9
- Materials list – including quantities by mass and details of grade or composition
- Documentation to support unload, installation & alignment
- Final alignment report (verification of installation alignment – must include raw data)

All documentation must be provided prior to delivery of the NBOA, with the exception of the final alignment report – see Section 9.

5.2 Project Management

The guide must be delivered to the ESS facility in Lund by the Supplier.

The detail needed for quotation regarding lead times is listed in the Tender Questions Documentation. The design freeze date and the delivery date will be agreed, based on tender return, and will be fixed as a part of the contract.

The contract will be with UKRI. The design approval and requirements management for the guide will be set by UKRI. UKRI will be retain all approval authority. It will be necessary for the Supplier to submit documents and support a preliminary design review, critical design review, final design review and final inspection report review for UKRI approval – the requirements for which are outlined in Section 9. Regular Skype updates and single page progress reports must also be supported.

Communication between the Supplier and ESS through UKRI is expected to be necessary during the delivery, installation and alignment. For all communications UKRI is expected to be kept informed and will remain the contract authority.

6 Technical Requirements

All materials used must comply with requirement outlined in Section 10.3

6.1 Super Mirror Guide

The required guide geometry is shown in drawing ESS-0106220.2. The bender must include 5 channels (4 silicon vanes). The vanes must be no thicker than 0.5mm.

All internal surfaces, that are exposed to the neutron beam, and both the convex and concave surfaces of the vanes, are to be coated with “m = 3” Ni/Ti supermirror. A minimum reflectivity of 99% must be achieved up to M=1. A minimum reflectivity of 85% must be achieved at M=3. Full reflectivity requirement definition is detailed in Section 10.

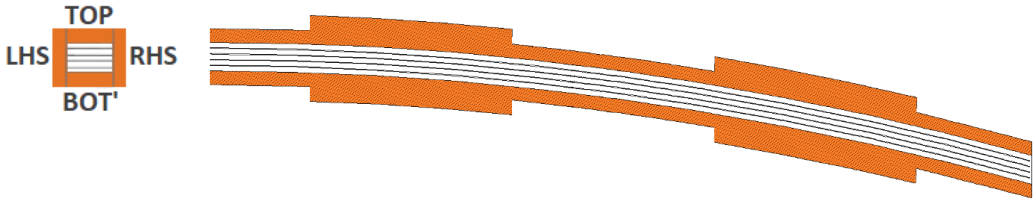

Figure 3 – Loki Guide Illustration

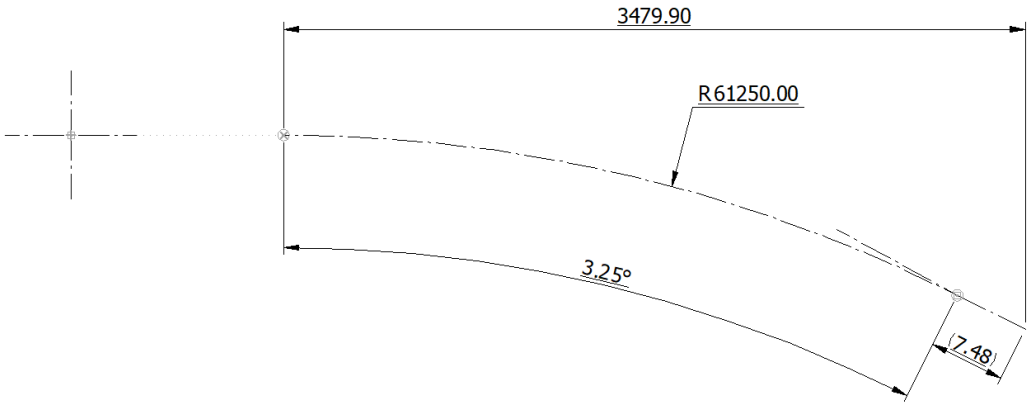

Figure 4 – Symbolic representation of the Guide Geometry

To allow for alignment and thermal expansion, small gaps between guide segments are permitted. These gaps are shown in the provisional design - drawing ESS-0106220.2. These gaps should be as small as practicable, the optimization of which, is included within the design scope. The Supplier must demonstrate that the solution proposed represents an optimum for the assurance of performance, quality and reliability and will be subject to approval by UKRI during the design reviews.

6.2 Substrate

The guide substrate must be made from high purity copper to the composition outlined in Section 10.3. Intended substrate thicknesses and lengths are shown in drawing ESS-0106220.2. Adjustments to these thicknesses can be accepted, but will be subject to UKRI approval at the reviews, and will be dependent on the Supplier demonstrating that the changes better assure performance, quality and reliability. The thicker section is required to block a potential shine path between the NBPI and the NBOA. The NBPI will be made to match this stepped contour and so block a shine path. The size of the step between thin and thick sections must not be decreased.

The precise construction of the substrate (numbers of pieces, how they interface and are joined) will be the responsibility of the supplier to design, and will be similarly subject to approval as above. The thicker sections, required to block shine paths between NBOA and NBPI, can be formed as a part of the substrate, or by the addition of material to the outside of the substrate. If additional material is added it must be in gapless contact with the substrate - Contact shall be maintained over >90% of adjacent surfaces.

The Supplier must provide drawings which detail the precise geometry that the NBOA will fill as a part of the design freeze (see Section 9).

6.3 Mounting & Alignment

The guide assembly must be aligned to the relative positions shown in drawing ESS-0106220.2. The Supplier will be responsible for aligning the guide within the NBPI relative to the NBPI survey network. The alignment devices must allow the guide to be aligned to the requirements outlined in Section 7. The alignment devices must support an adjustment range of ±2mm about the nominal. The alignment device must maintain accuracy for the life time of operation, in the operating conditions outlined in Section 6.5.

The design of the alignment devices will be the responsibility of the Supplier. A provisional requirement has been set by ESS, for the alignment devices to be operable with access, through the NBPI, from one side only. This access is shown in Figure 5. This requirement is driven by thermal and neutronic parameters. Access from above for installation will be possible through a removable lid. Provisional positions, sizes and mounting features for the alignment devices are shown in drawing ESS-0106220.2. These characteristics can be optimized as a part of the design activity, and will be subject to approval by UKRI, the Supplier will be required to demonstrate that the design best assures performance, quality and reliability. The Supplier must provide drawings which detail the precise interfaces with the NBPI as a part of the design freeze.

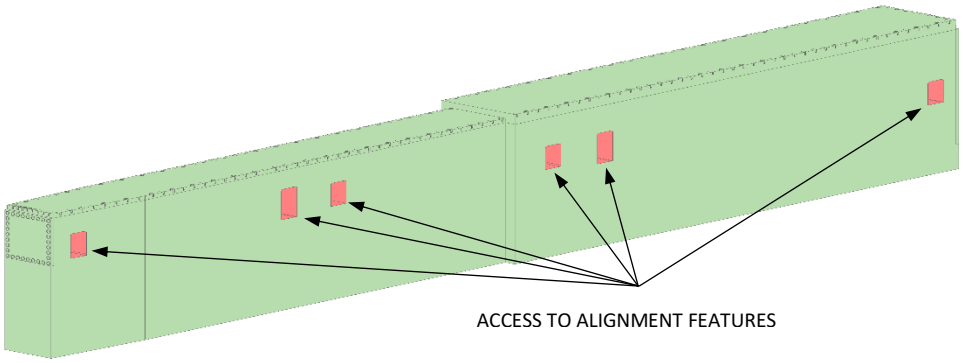

Figure 5 – Provisional NBPI Design (Access through to Alignment Features)

It will be the responsibility of the supplier to design and define the installation, survey and alignment methodology. The Supplier will be responsible for designing and providing suitable handling and lifting features to enable safe installation. As indicated in Section 9 these methodologies and solutions must be presented at the reviews and will form a part of the approval assessment. As a part of this the Supplier will be responsible for demonstrating how the survey and alignment methodology enables and ensures the requirements outlined in Section 7.

6.3.1 Retention, Decommissioning

At end of service life the NBEX will be removed and treated for disposal. During decommissioning, the NBEX and contained NBOA components will be sectioned at the point indicated in Figure 6. The design of the guide, mounting and alignment devices must ensure that, following sectioning, guide segments are retained within the cut volumes of the NBPI see Section 6.5.2. Fracture of the vanes is acceptable and will require no special provision. This decommissioning exercise does not form a part of the scope of work.

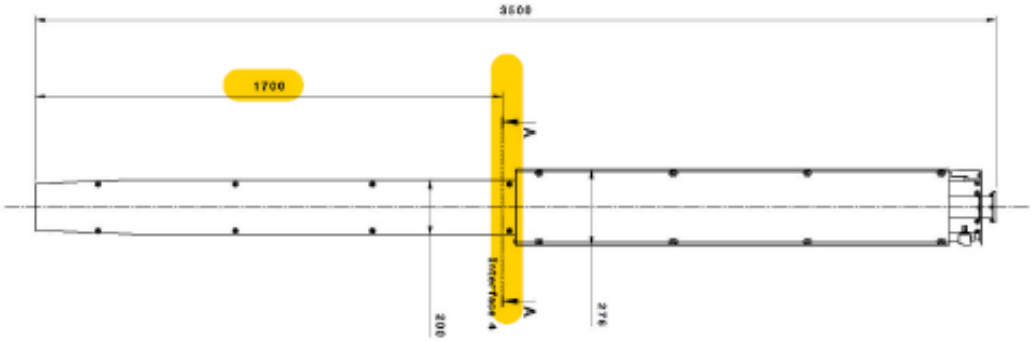

Figure 6 – Decommissioning section line

6.4 Maintenance

There will be no accessibility for maintenance for the life time of the NBOA.

6.5 Operating Conditions

Table 3 and Table 4 give the operating conditions for, normal operation and during shutdown respectively. The facility will cycle approximately 5 times per year between operation and shutdown. The NBOA will be required to operate for 20 years without degradation affecting performance. During operation the vessel shall remain closed and contamination of the atmosphere through degassing of components must be minimised. All components and assemblies shall be designed for the vacuum bake and the helium environment.

Operation	**nominal**	**limits**
Temperature	60°C	40 – 60°C
Atmosphere	Helium 1.1bar absolute H2O contaminant <60ppm	1.2 mbar - 1.1bar absolute
Exposure (at 5MW)	Neutron capture flux (cold/thermal): $\Phi = 5\times10^{10}$ $cm^{-2}.s^{-1}$ Neutron capture flux (epithermal): $\Phi = 5\times10^{10}$ $cm^{-2}s^{-1}$ High energy hadron flux (1MeV-2GeV): $\Phi = 5\times10^{12}$ $cm^{-2}s^{-1}$ X-ray to Gamma flux (1KeV-2GeV): $\Phi = 5\times10^{12}$ $cm^{-2}s^{-1}$	
Duration p.a.	4000hr per yr.	4000 – 6000hr per yr.

Table 3 – Operating conditions for normal operation

Shutdown	**nominal**	**limits**
Temperature	20°C	10 - 60°C
Atmosphere	Helium 1.1bar absolute H2O contaminant <60ppm	1.2 mbar - 1.1bar absolute
Exposure	X-ray to Gamma flux	
Duration p.a.	4000hr per yr.	2700 – 4000hr per yr.

Table 4 – Operating conditions during shutdown (no beam to target)

Helium fill prep	**nominal**	**limits**
Temperature	60°C	40 – 60°C
Atmosphere	Vacuum $1x10^{-4}$mbar	$1x10^{-8}$ mbar - 1.1bar absolute
Exposure	Not applicable	NA
Duration	16hrs	16hrs

Table 5 – Operating conditions during vac & bake for He fill

6.5.1 Helium Fill and Vacuum Bake

Following installation and alignment of components within the beam port insert, the vessel shall be closed and prepared for operation within a pure helium atmosphere. The whole assembly shall be evacuated and heated to promote degassing and removal of volatile contaminants. This process will be completed by ESS.

6.5.2 Earthquake Events

The NBOA must retain full functionality and correct alignment following 0.4G acceleration in any plane due to an earthquake.

The NBOA guide segments must be physically restrained such that they cannot move more than 2mm along the beam axis when subject to 2G acceleration in any plane due to an earthquake. This physical restraint should be by means of a pin - such that their fitness for purpose, can be reliably validated in the design phase. These same physical restraints should be used to ensure, and should align with, the requirement outlined in Section 6.3.1.

7 Quality

7.1 Alignment Accuracy

The guide reflective surfaces must be manufactured and aligned to within a profile tolerance of 0.04mm, relative to the theoretically exact geometry. The actual centre line must be aligned to a positional tolerance of 0.02mm relative to the theoretically exact centre line.

7.2 Segment length error

Segment length error is defined as the deviation of the length of the assembled guide unit as measured between the entry and exit faces along the guide axis. The maximum permissible deviation from the nominal values is ±0.2mm

7.3 Step alignment error

Step alignment error is defined as lateral positioning error between subsequent individual guide elements, substrates or surfaces within an assembled unit. The step alignment error shall be < 0.02mm.

7.4 Waviness

Waviness is defined as: the angular deviation from a perfectly flat surface. On all reflective surfaces the angle between any two surface normals must remain within a cone of semi-angle < $1.5x10^{-4}$ radian RMS (Root Mean Square deviation). The maximum peak value of acceptance of any point is < $3.5x10^{-4}$ radian.

7.5 Local Defects

On all coated surfaces, the cumulative surface of all scratches, greyness, open bubbles, scuff marks, sleeks or other defect shall remain < 0.02% of the total useful area of the component.

7.6 Internal Stress

To avoid degradation of the super mirror, internal stresses are to be minimised by a suitable manufacturing or annealing process.

7.7 Quality Control and Assurance

The NBOA components and completed assembly must be inspected and validated to verify compliance to the specification. The supplier must provide a detailed quality control and assurance plan at the CDR. The completeness of which shall form part of the review approval criteria. The plan submitted at CDR must demonstrate how the quality control and quality assurance steps planned and taken will ensure compliance to each specification clauses.

Mandatory quality control measurements include:

- Material grade / composition certificates
- External geometry measured for compliance with final approved drawings
- Reflectivity tests – must be completed on a representative sample (min 10%)
- Final alignment survey (from installation and alignment in the NBPI)

The plan must be followed and the results documentation provided at the final inspection report review as detailed in Section 9. The final alignment report must be supplied within 5days of completion of the installation, and the raw data must be made available to UKRI & ESS within 24hrs.

7.8 Product Marking

Each component and subassembly shall be permanently marked on an exposed housing surface with the Seller's name and the appropriate subassembly part number. The marking shall be in accordance with Section 4.1 of AS478, using machine engraving, chemical etching or stencil blast. Character height shall be approximately 6mm.

8 Installation at ESS

Risk assessments and method statements must be submitted by the supplier prior to, delivery, installation and alignment. These must cover all unload, installation and alignment processes. Installation personnel will be required to undergo ESS training as a part of their induction to work on site (as outlined in ESS-0147100 Rev 1) and must conform to site rules (as outlined in ESS-0147089 Rev 1). Installation activities must be completed in accordance with Swedish regulatory requirements. The Supplier will bear the costs associated with fulling these regulatory responsibilities (training, certification or alike). Lifting features and equipment must comply with relevant Swedish and European regulations.

All contractors operating on site must be in possession of a valid ID06 card See Section 6.3 of ESS-0147089 Rev 1. – More information is available at https://www.nexusid06.se/en

9 Approvals & Reviews

Below are details for the required content of the design and documentation reviews. Any outcome of the design reviews shall not relieve the Supplier from the responsibility of delivering to the specification or the contracted delivery date.

All reviews can be held at the Supplier site, UKRI or ESS – to be decided by mutual agreement. All reviews must include an UKRI engineer and key members of the Supplier engineering and design team. It may also include an ESS representative.

UKRI or ESS staff may, at points during the contract, require access to visit the Supplier manufacturing site and carry out inspections and progress checks. Such visits must be accommodated by the supplier.

9.1 Preliminary Design Review (PDR)

To be held within the first 2weeks of the contract commencing. At the PDR the Supplier must present:

- Summary of the requirements
- Concepts for the alignment mechanism
- Concepts for the guide construction
- Concepts for the Installation, survey and alignment process
- Project schedule
- Primary project risks and mitigation measures

Design details will be reviewed and agreed. It may be necessary for further work to be carried out to clarify certain elements before the PDR is passed. As such 2weeks must be allowed in the project schedule for the complete PDR process.

9.2 Critical Design Review (CDR)

To be held once the engineering design work is completed, but before detailed drawings are created. At the CDR the Supplier must present:

- Summary of how the key points within the specification have been meet
- Description of any changes that are required to the interface with the NBPI
- Summary of engineering validation work undertaken
- Detailed inspection and validation plan (as outlined in Section 7.7)
- Project schedule
- Outstanding project risks and mitigation measures

This review will act as a project gate to verify that the design does align with the customer expectation. It may be necessary for further work to be carried out before the CDR is passed. As such 2weeks must be allowed in the project schedule for the complete CDR process.

9.3 Final Design Review (FDR)

To be held once all design work is completed and the design can be frozen, including all tolerances. At the FDR the Supplier must present:

- Detailed drawings of the NBOA
- Any changes to the design since the CDR
- Project schedule
- Outstanding project risks and mitigation measures

The Supplier must submit the detailed drawings of the NBOA. This review will act as a project gate to verify that the design aligns with the customer expectation and will freeze the design. It may be necessary for further work to be carried out before the FDR is passed. As such 2weeks must be allowed in the project schedule for the complete FDR process.

9.4 Final Inspection Report Review

To be held after completion of the manufacturing and validation, prior to delivery to ESS. At this review the Supplier must present:

- Inspection reports
- Validation test reports
- Project schedule
- Outstanding project risks and mitigation measures
- All further project documentation as outlined in Section 7.7

This review should be a formality only and no further work should be required. The installation and alignment date will be finalized at this point.

10 Technical Definitions

10.1 M value

The M value describes the minimum critical angle of reflectivity, with respect to the critical angle of a natural Ni coating (m × 1.73 mradian/Å).

10.2 Reflectivity

The guide coatings are specified to achieve a minimum critical angle of m times the critical angle of a natural Ni coating (m × 1.73 mradian/Å). For all coatings, the neutron reflectivity is expected to be 99% or greater up to a critical angle of m = 1 (Q_c^{Ni}).

Depending on the coating, a minimum (Q_c^{min}) and average (Q_c^{avg}) critical cutoff, and a minimum (R_{Qc}^{min}) and average (R_{Qc}^{avg}) reflectivity at that critical cutoff are specified. The quality of the supermirror coating on an individual piece is not solely determined by its reflectivity at the nominal supermirror critical angle. The reflectivity profile between Q_c^{Ni} and Q_c^{avg} must decline, on average no faster than, linearly between the R_0 = 0.99 value at Q_c^{Ni} and R_{Qc}. Based on this characteristic, requirements are placed on the integrated reflectivity over the entire curve for both minimum and average pieces.

The area under a simplified supermirror reflectivity curve, such as that shown in Figure 8 are given by the following expression:

$$A = Q_c^{\mathrm{Ni}}\left[R_0 + \frac{1}{2}\left(R_0 + R_{Qc}\right)(m-1)\right].$$

The minimum required area under the normalized reflectivity curve for any piece is A_{min}, likewise, the area under the required average reflectivity curve is $A_{avg.}$. The parameters for the guide coating described in this specification are provided in the table below.

	m=3.0
Q_c^{min}	2.9 Q_c^{Ni}
Q_c^{avg}	3.0 Q_c^{Ni}
R_{Qc}^{min}	0.83
R_{Qc}^{avg}	0.85
A_{min}	0.059 Å^{-1}
A_{avg}	0.059 Å^{-1}

Table 6 – Coating Requirements

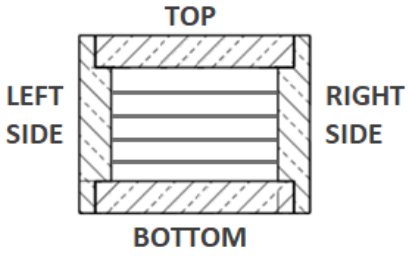

Figure 7 – Illustration of Section Definition

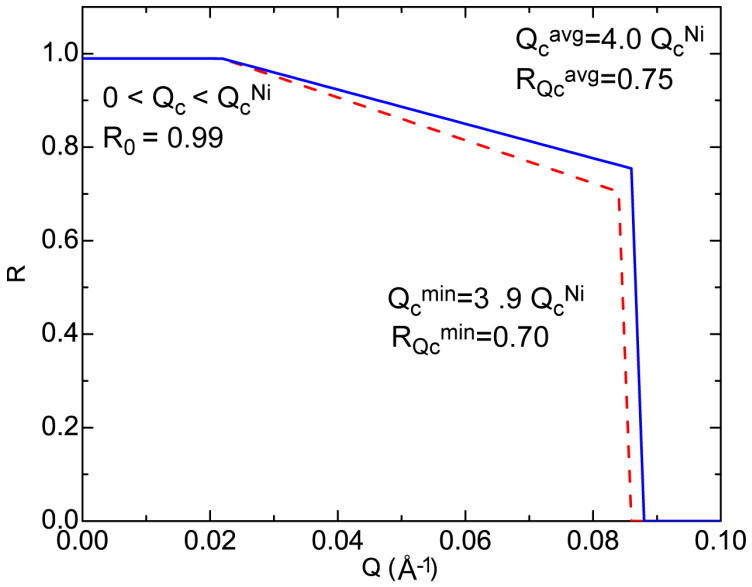

Figure 8 – Example Reflectivity Curve

10.3 Material Compositions

ESS Licencing rules require strict control over the materials used. Section 6 states the materials that must be used for the substrate and vanes. All other parts of the NBOA must be made from the materials listed below. The use of other materials will only be permitted in exceptional circumstances, justification will be required and will be subject to discretional approval by UKRI (must be agreed prior to CDR approval)

Name	Descriptor	Grades/Compositions
High Purity Copper	Oxygen free (OF) pure copper	UNS C10100; CW008A; DIN 2.0040-Cu OF
Stainless Steel	Low carbon Stainless Steel	UNS S31603; EN 1.4404; AISI 316L
Aluminium alloy		AA 5083; ISO 3.3547; DIN AlMg4.5Mn
Aluminium alloy		AA 5754; ISO 3.3535; DIN AlMg3
Aluminium alloy		AA 6081; ISO 3.2315; DIN AlMgSi1
Aluminium alloy		AA 2017A; ISO 3.1335; DIN Al-4Cu-1Mg
Low alloy steel	Carbon (non-alloy) steel	AA S235JR; ISO E24; DIN EN 10025
Nickel	Allowable as coating only	
Titanium	Allowable as coating only	

10.3.1 Controlled substances

The substances listed in Table 7 are known to present issues with regards to activation. As such their use is discouraged. Any requirement to include them will require justification

Substance	Concentrations	Current ESS Strategy
Antimony	% in lead	
Cobalt	<0.1% in steels	Use mild steel, copper, certified low Co stainless steel.
Europium	PPB in concrete	Do not expose concrete to activation.
Gold	0.01%	
Inconel		Avoid where possible
Molybdenum	% in stainless steels	Use mild steel, copper, certified stainless steel.
Silver	0.02%	Impurity in lead and other heavy metals, Ag-110 is a problem above ~0.02% mass levels in lead.
Tin		Ingredient in bronzes, but also zircaloy4, creates a long term issue in the form of Sb-125 (10 µSv/h contact dose)
Tungsten		Avoid where possible
Uranium		Do not use it.
Zinc		Activates in brasses, and when used as plating in mild steel it forms oxides as fine white powder. Despite Co content in Ni, all plating on mild steel near the neutron beams must be Ni.

Table 7 – Controlled Substances